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CONSTRUCTING WITH ENGINEERED BAMBOO

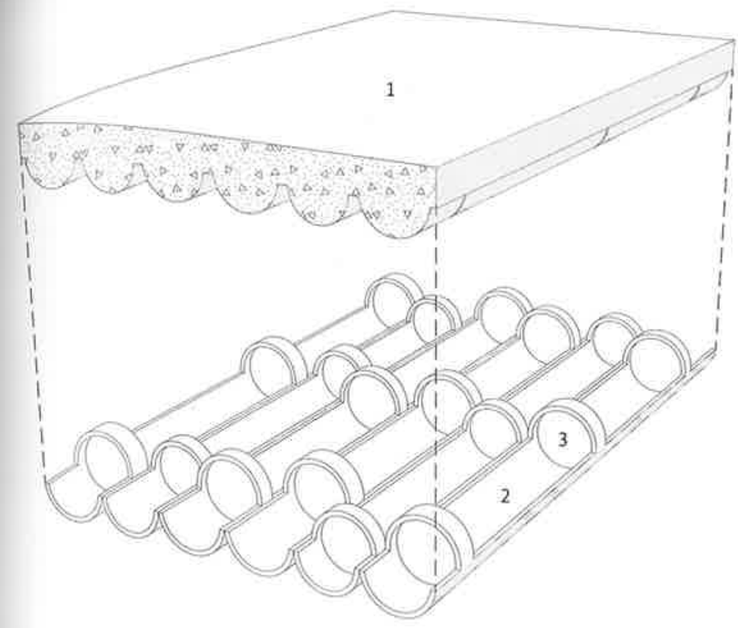
Dirk E. Hebel, Felix Heisel, Alireza Javadian, Philipp Müller, Simon Lee, Nikita Aigner, and Karsten Schlesier

▴ The SEC/FCL Advanced Fibre Composite Laboratory in Singapore conducts research on various speci of bamboo to understand specific a varying characteristics of the grass

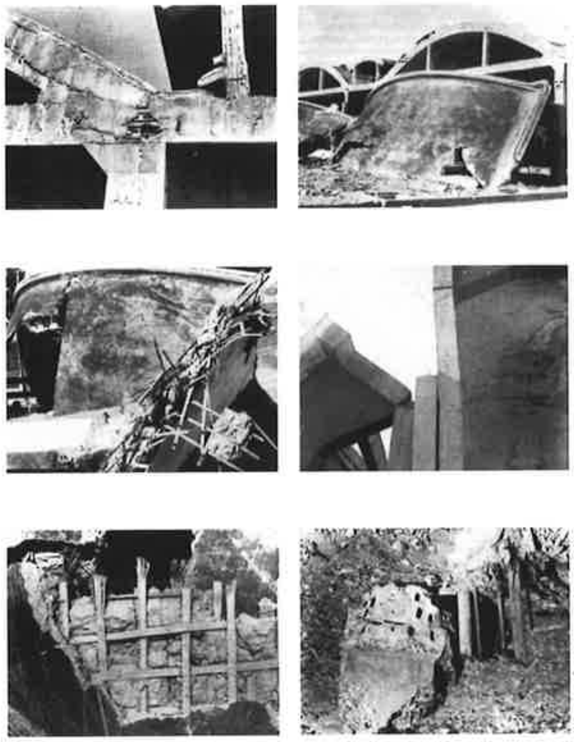
Status quo: Raw bamboo in industrialized construction

Interest in bamboo as an industrialized construction material can be traced back to the year 1914, when PhD student H. K. Chow of the Massachusetts Institute of Technology (MIT) tested small-diameter bamboo and bamboo splits as reinforcement materials for concrete. Following this very first study, other researchers and research institutions around the world started experimenting with raw bamboo to replace steel reinforcement specifically for reinforced concrete beams and slabs. Among them was the University of Stuttgart in Germany, at that time a Technische Hochschule, where in 1935 Kramadiswar Datta and Otto Graf tried to find appropriate applications for the outstanding mechanical and technical properties of bamboo, unfortunately without any sustained success.[1]

In 1950, Howard Emmitt Glenn of the Clemson Agricultural College of South Carolina (now Clemson University) started to conduct more extensive research.[2] He and his team tested bamboo-reinforced concrete applications by erecting several full-scale buildings, utilizing his experience from work he had conducted in 1944 on bamboo-reinforced concrete beams. Using only small-diameter culms and bamboo splits, he demonstrated that the application was feasible; however, bamboo's elastic modulus, its susceptibility to insect and fungus attacks, the coefficient of thermal expansion, and a tendency to shrink and swell represented major challenges. Glenn applied different methods to minimize these defects, with varying success. Covering the bamboo components with coatings before placing them into the concrete mix, for example, reduced their exposure to moisture



1 Concrete slab
2 Partially split bamboo as lost formwork
3 Interlocking diaphragms



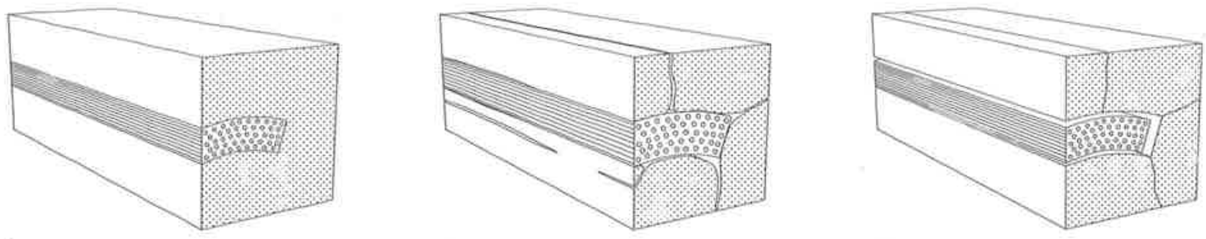
and the alkaline environment of concrete. Eventually, however, the results showed that the solutions applied were rather expensive and the final product was unable to compete with steel reinforcement in economic terms. Besides, the long-term behaviour of bamboo reinforcement in concrete structures posed unsolvable problems for Glenn. As a natural material, bamboo absorbs water and moisture either from the moist environment of concrete during curing or through micro-cracks over longer periods of time. Water absorption leads to a progressive degradation of the bamboo culms and splits due to excessive swelling, resulting in a loss of bonding with the concrete. In the end, the structural members of Glenn's prototypes failed and the buildings collapsed.

In the following years, the United States military started to show growing interest in bamboo-reinforced concrete as an inexpensive and local solution for their increased construction activities in the tropics. In February 1966, Francis E. Brink and Paul J. Rush carried out a project for the US Naval Civil Engineering Laboratory at Port Hueneme in California in which they made suggestions for the design and construction with bamboo-reinforced concrete as well as the selection and preparation of bamboo for the making of reinforced concrete.[3]

Based on these results, in 1970, Helmut Geymayer and Frank Cox from the US Army Engineer Waterways Experiment Section studied the application of a local bamboo species from Mississippi, *Arundinaria tecta*, for reinforcing concrete beams and slabs.[4] Concrete beams with a reinforcement ratio of three to four per cent were prepared, using bamboo splits that were either coated with an epoxy and polyester resin or pre-soaked for 72 hours before placing into the concrete matrix. The results showed that bamboo-reinforced concrete beams could develop about three to four times the maximum flexural strength of unreinforced beams of the same cross sections. As to cracking and failure, the results confirmed the conclusions by Glenn on the bonding behaviour of bamboo-reinforced concrete beams: due to different thermal expansion coefficients of bamboo and concrete and the ensuing thermal strains, cracking seemed unavoidable. This points at an important fact: while bamboo offers very high tensile strength, the low bonding strength between concrete and bamboo as a result of continuous swelling, shrinking, and differential

◂ Khosrow Ghavami used raw bamboo culms which were partially cut while leaving the nodes intact, to construct a lost formwork for concrete applications.

▸ Used in the construction of military hangars in Korea, raw and untreated bamboo splits de-bonded from the concrete matrix due to swelling and shrinking of the organic material and caused the structures to collapse (images published by Oscar Hidalgo-Lopez in *Bamboo: The Gift of the Gods* in 2003).



1 Natural bamboo placed in fresh concrete
2 Cracks caused by swelling of bamboo
3 Deponding due to bamboo shrinkage

thermal strains impedes the extensive application of bamboo as reinforcement for concrete elements.

In 1995, Khosrow Ghavami of the Pontifical Catholic University of Rio de Janeiro started a new series of mechanical tests on seven different types of bamboo. He hoped to determine which was the most appropriate species for use as reinforcement in newly developed lightweight concrete beams. The results demonstrated a remarkable superiority in terms of the ultimate applied load they could support compared to reinforcement with steel bars. However, the long-term behaviour of bamboo in concrete structures still remained problematic. Ghavami concluded that the different thermal expansion coefficients of bamboo and concrete would inevitably result in the de-bonding of the two materials.

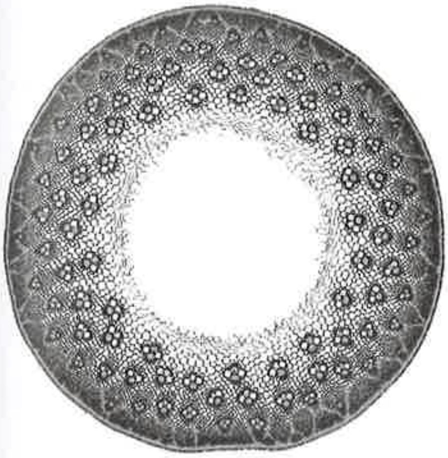
Ten years later, Ghavami published a detailed study of bamboo reinforcement for a wide range of applications including concrete slabs, columns, and beams.[5] The bond behaviour of bamboo reinforcement to the concrete matrix was studied in this investigation through series of pull-out tests. Treated with an epoxy-resin bonding agent, the bamboo reinforcement showed an increased bonding strength that was 5.29 times higher than untreated bamboo reinforcement.[6] To create concrete slabs, Ghavami arranged treated, half-split bamboo culms next to each other before covering them with a layer of concrete, utilizing the bamboo as both tensile reinforcement and permanent (lost) formwork. To improve the mechanical interlocking between bamboo reinforcement and concrete, a composite interface was created between the two materials by leaving the bamboo nodes intact when cutting the culms. Unfortunately, also these concrete slabs failed, mostly due to de-bonding and crushing of the culm sections and eventually due to concrete compression failure.

In the end, Ghavami's experiments have shown that replacing steel reinforcement in concrete applications is possible thanks to the superior mechanical properties of bamboo. But the problems with bonding and shear strength as well as durability of natural bamboo in the concrete matrix remained major barriers against a widespread application of bamboo as reinforcement in concrete applications.

Several other studies[7] have confirmed that natural bamboo could potentially replace steel in concrete applications, even though the ultimate load-bearing capacity of the concrete members reinforced with natural bamboo was less than 50 per cent of steel-reinforced concrete members. Yet these investigations did not elaborate on the main problem of using natural bamboo in concrete: (de)bonding.

In 2011, Masakazu Terai and Koichi Minami of Kindai University in Japan carried out series of pull-out tests as well as tests on bamboo-reinforced concrete slabs, beams, and columns.[8] A synthetic resin coating was applied on the surface of the reinforcements, which proved to enhance their bond strength. The reinforced concrete slabs showed signs of bond failure during the bending test, but the concrete beams and columns showed superior performance compared to non-reinforced members. Terai and Minami demonstrated that the

▲ **Effects of swelling and shrink and the resulting de-bonding of untreated bamboo when used a reinforcement system in concre applications.**

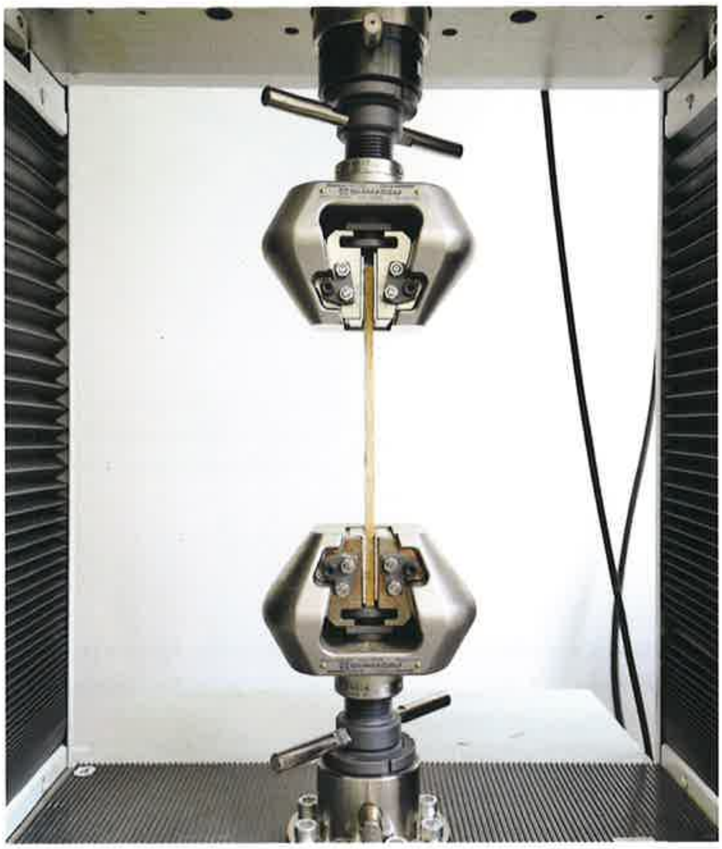


fracture behaviour of bamboo-reinforced concrete members can be evaluated by the existing formula for reinforced concrete members. But again, the results also indicated that the bonding strength between bamboo reinforcement and concrete matrix was only half of that of deformed steel reinforcement and concrete.

Makoto Yamaguchi, Kiyoshi Murakami, and Koji Takeda of Kumamoto University in Japan carried out a series of four-point bending tests of reinforced concrete beams with Moso bamboo reinforcement and stirrups.[9] The investigation showed that the load-bearing capacity of the bamboo-reinforced concrete beams could be predicted by section analysis based on the Bernoulli-Euler beam theory. However, this research did not investigate the effect of bamboo stirrups on shear failure and shear resistance capacity. Several further universities in Nigeria and India conducted similar research in recent years to evaluate the suitability of natural bamboo as a replacement for steel in concrete applications.[10] In all these investigations, bamboo proved to be a suitable replacement for steel reinforcement as far as its high tensile and flexural strength is concerned – yet did not measure up to steel in terms of bonding and durability.

▴ Bamboo culm cross section showing the vascular bundle structure.

▾ Newly developed bamboo composite material at the SEC/FCL Advanced Fibre Composite Laboratory.



As a conclusion, the research conducted so far in the field of bamboo-reinforced structural concrete applications specified two major findings. Firstly, replacing steel with bamboo material as a reinforcement system is feasible. Secondly, so far, no solution is available to improve durability and control the swelling, shrinking, and thermal expansion of the material. In a way, these results are valid to the industrialized use of bamboo in the construction sector as a whole. Since the beginning of the 21st century, there has been a global effort to apply the developments from the timber industry to bamboo as a resource, fighting with the plants' very specific organic properties, as further described by Pablo van der Lugt and Felix Böck in their contributions (see pp. 72, 86).

Methods of engineering bamboo

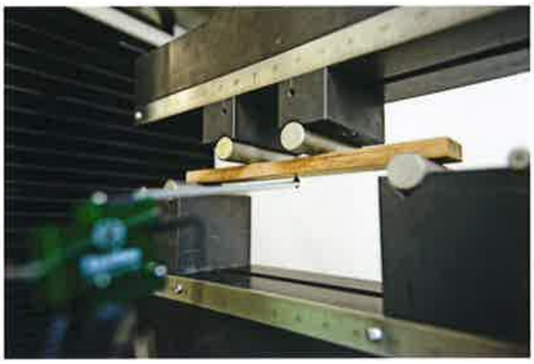
Extensive research began in 2012 at the Future Cities Laboratory in Singapore and the Federal Institute of Technology ETH Zürich of Switzerland, exploring the development of a novel engineered bamboo material. Joined in 2013 by industrial partner Rehau and in 2014 by research partner Empa, the collaborative aim is to produce a high-strength, formable, water-resistant, non-swelling, non-corrosive, and durable biologically based composite material that takes advantage of bamboo's superior physical properties while mitigating its undesirable qualities. Departing from all former approaches, fibre bundles are extracted from the natural bamboo culm and treated to achieve the desired properties before binding them back together. The characteristics and the form of the resulting composite can be manipulated according to the desired product. Through such engineering, the biological bamboo material is being enabled for an industrial production process.

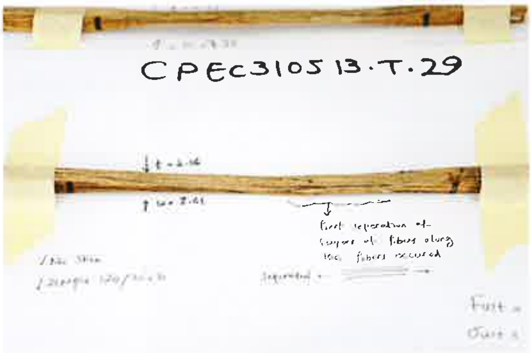
To this purpose the current research focuses on three areas: treatment of the fibre, appropriate adhesives, and a standardized production process.

The treatment of the fibre[11] is crucial to the success of the project. Only if the capacity of the fibre stays intact during extraction and composition, the

◂ Tension test of the newly developed bamboo composite material, performed in accordance to Eurocode and the standards of the American Society for Testing Materials, ASTM International.

▸ Pull-out test sample of the newly developed bamboo composite material.





◂ Bone-shaped test sample of the newly developed bamboo composite material. The material is in accordance with the European standard, Eurocode, and the standards of the American Society for Testing Materials, ASTM International.

▸ Test samples before testing.

◂ Microscopic investigation of test samples and their behaviour at the SEC/FCL Advanced Fibre Composite Laboratory.

▸ Four-point bending test of the newly developed bamboo composite material, performed in accordance to Eurocode and the standards of the American Society for Testing Materials, ASTM International.

◂ All test samples of various test series at the SEC/FCL Advanced Fibre Composite Laboratory are documented, catalogued, and stored at the facility.

▸ Investigation of material behaviour.

naturally existing properties will be maintained. This is the most important difference from existing products in the market, which usually lose the inherent strength of the natural material as it is exposed to harmful treatment procedures. Tests on floorboards or kitchen tops of such kind, for example, show a dramatic decline of strength compared to the untreated bamboo material.

The second focus, the development of effective adhesives,[12] investigates the behaviour of and interplay between organic and inorganic materials. The adhesive matrix controls factors such as water resistance, thermal expansion, and refractability.

The third aspect, the standardization of the production process, is crucial also for production in developing countries in order to guarantee safety factors and certify the product as a building material. As bamboo is still, in most countries, not considered to be an industrial, processed resource, standardization criteria and systems need to be developed so as to conduct research according to the strictest possible scientific terms.

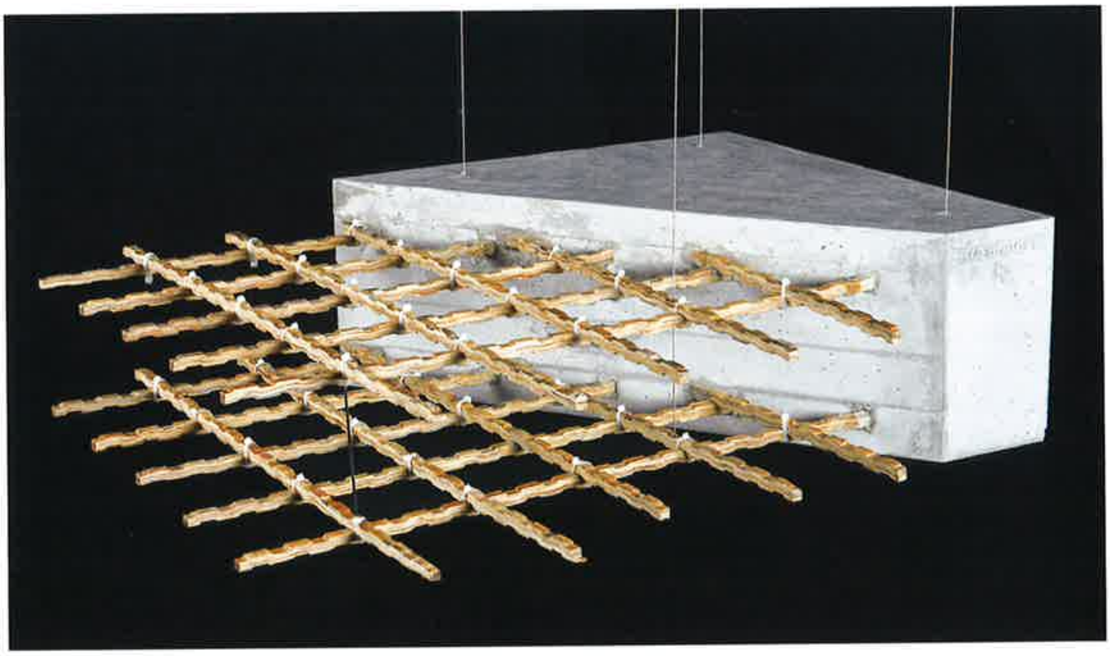
Engineered bamboo as a reinforcement system in concrete applications

Steel-reinforced concrete is the most common building material in the world. The developing countries use close to 90 per cent of the cement and 80 per cent of the steel consumed globally by the construction sector. At the same time, very few developing countries have the ability or resources to produce their own steel or cement, forcing them into an exploitative import relationship with the developed world. Out of 54 African countries, for instance, only two produce steel on a significant level above 4 megatons per year.[13] But steel is not irreplaceable. Bamboo is in principle available in those areas of the planet which are expected to have the highest share of construction activities in the decades to come, including Africa.

◂ Pull-out test of the newly develo bamboo composite material, performed in accordance to Eurocode the standards of the American Soci for Testing Materials, ASTM Intern tional.

▸ Four-point bending test of a bam composite reinforced concrete bea at the SEC/FCL Advanced Fibre Com posite Laboratory.

▾ First applications of the newly developed bamboo composite mat al as a reinforcement system in co crete.



▸ Pull-out test samples at the SEC/FCL Advanced Fibre Composite Laboratory. Here, the bonding between the new material and the concrete mix is tested.

▾ Testing scenario to measure the thermal expansion of the bamboo composite material in concrete.

Research at FCL Singapore and ETH Zürich investigates transforming natural bamboo into an easy-to-handle fibrous material, which is then fabricated into a high-tensile-strength composite using a hot-press method. Various species have been tested, all already used in construction and widely available. In each case, the raw material consists of an average fibre collection from the upper, middle, and lower sections of the bamboo culm, in nearly equal ratios. Also represented are the properties of all layers of a bamboo culm, acknowledging the varying properties of a naturally grown material in order to enable easy application of an industrialized process. Today, the Advanced Fibre Composite Laboratory at FCL Singapore is able to produce a bamboo composite which can compete with a low-grade steel reinforcement system in terms of tensile as well as bending strength.[14] The reinforcement system consists of longitudinal rebars and stirrups integrated into a concrete mix. In testing, these elements reach the same and even higher system properties in terms of bending capacity compared to a steel-reinforced system with identical reinforcement diameters.[15]

Moreover, extended pull-out test series proved that the newly developed bamboo composite material has highest bonding capacities with the concrete matrix, providing a solution to the described issues of durability in earlier investigations.[16] This is partially guaranteed by controlling the thermal expansion of bamboo through the adhesive matrix, as well as the composite's very low water absorption. The research so far confirms that by varying and controlling the process conditions (pressure, temperature, time) during

fabrication of the composite material, as well as enhancing the communication of the material towards other milieus (e.g. concrete's very high PH level), it is possible to tune the mechanical properties of a biological composite material into ranges that can in the future compete with tensile capacities of metallic as well as synthetic materials – at significantly lower cost. To reach this state, questions of standardization in the production process require further attention.

Multi-directional bamboo fibre-reinforced composites

In recent years, building industries around the globe have competed in developing lightweight materials with extreme tensile strength capacities. Materials of this kind find applications in aerospace industries, specialized building industries like mining and tunnel construction, and lately also in the automotive industry. All of these materials are composites. A symbiotic composite is typically

▴ **Bamboo composite reinforceme[nt] system as tested at the SEC/FCL A[d]vanced Fibre Composite Laborato[ry]**

▾ **Sample beams after testing.**

▲ Vacuum moulding allows new application fields.

▸ Under vacuum, the adhesive is being pulled as thin and evenly as possible into almost any material configuration.

▾ Bamboo fibres could replace non-organic fibres in thin-shell applications.

created by mixing industrially produced synthetic inorganic fibres with an adhesive agent, resulting in a high-strength and at the same time lightweight material. However, conventional composite production is tedious and therefore extremely expensive. Raw materials such as glass or carbon fibres are hard to handle, represent a finite resource and usually require high amounts of energy in production, while at the same time they usually cannot be recycled and therefore end up as problematic waste after use. These are drawbacks that limit the access of such materials to high-end applications.

All renewable materials containing lignocellulosic fibres are promising candidates for creating a viable alternative to this situation: by developing bio-based composites that can be used for structural applications. Among these, bamboo fibres are a highly promising alternative to synthetic fibres due to their high mechanical qualities, low cost, cultivated abundance, and CO_2 storage capacity. So far, the major drawback for the application of bamboo in the composite industry has been the tedious and challenging fibre extraction process that reduces the mechanical qualities of bamboo fibres, making them weaker and therefore less attractive for the use in reinforced composites.[17]

The novel mechanical processing technique developed at FCL Singapore and ETH Zürich improves this fabrication process and its results. The developed bamboo fibre composites demonstrate that bamboo fibres can be used to create multidirectional fibre-reinforced materials. Similar to its synthetic counterpart, multidirectional fibre orientation within the composite can be achieved by

stacking up a number of bamboo fibres with specified angular orientations and adding a matrix system through vacuum infusion or a press. The result is a thin, yet strong and stiff multidirectional bamboo fibre composite that has properties comparable to glass fibre-reinforced plastics. This possibility to turn bamboo fibres into a multidirectional material is a crucial factor for the development of load-bearing applications: in the majority of applications, complex multidirectional loading states occur. By aligning the load-carrying bamboo fibres with the direction of the occurring loads, the load-carrying ability of the bamboo fibre composite can be increased and its mechanical properties optimized in terms of stiffness, strength, and weight.

The low cost of bamboo, its superiority in terms of biological availability over synthetic reinforcement fibres, and its good mechanical performance are key factors that lend multidirectional bamboo fibre-reinforced composites a huge potential. Bamboo as a cultivated alternative could replace commonly used structural materials in the automotive sector, the building and construction sector, the wind energy sector (as a structural material for wind turbine blades[18]), or in the sporting goods sector. Furthermore, especially in developing regions in Africa, Asia, and South America where the scarcity of fossil and forest resources imposes the use of agricultural crops for the design and development of polymer composites, bamboo-based durable and strong composite materials will be of vital economic importance in the near future.

Bamboo-reinforced construction timber

Recent developments in timber construction, especially in the field of multi-storey residential structures, increasingly require innovative, high-performance, wood-based building materials and techniques. The bamboo composite materials as developed at the Advanced Fibre Composite Laboratory at FCL Singapore and ETH Zürich can be adopted to overcome shortcomings of wood, in particular its limited shear strength or brittle failure in tension, limitations which currently restrict the application of wood as a load-bearing material in building structures. There are three specific areas

▲ In the future, wind rotor blad could be manufactured out of n fibres such as bamboo.

where bamboo composite reinforcements of timber structures may increase the performance of structural timber: bending reinforcement, shear reinforcement, and tension reinforcement perpendicular to the grain.[19]

Inlays of bamboo fibre composites into the joints of glued laminated timber represent a possibility to compensate for general shortcomings of timber such as a brittle failure in tension/bending and a high degree of variation in terms of mechanical strength. Inlays with a thickness of one to two millimetres can easily be placed in the joints during production to bridge imperfections such as branches or growth irregularities that are liable to cause failure, especially in the tensile zone. This bridging effect results in a lower degree of variation of the load-bearing capacity and thereby a higher degree of structural safety. As another result, material consumption can also be reduced. A particular feature is that the bamboo fibre composite inlays are able to shift the brittle failure in the bending-tension zone to a ductile failure in the bending-compression zone. In this way, overload can be monitored and failure can be predicted by the wrinkling of the fibres in the compression zone.

Bamboo fibre composite material is also of great interest for timber connection systems. Timber connections are commonly produced using steel plates and laterally loaded dowel-type fasteners, connections which are easy to design, produce, and assemble and yield a high load-bearing capacity. However, the heat transfer of metallic components leads to a rapid temperature increase in the connection, reducing the load-bearing capacity in case of fire and as a consequence the fire resistance of the entire structure. Furthermore, metallic components cannot be used in chemically harsh environments and where non-magnetic and/or non-conductive properties are required.[20] Bamboo fibre composites have the potential to replace steel as fastener in many applications.

The strengthening of timber with technical fibres by using finite resources such as oil (carbon fibres) or sand (glass fibres) requires large amounts of energy during production. This conventional combination threatens the major comparative advantage of wood as a fully natural, renewable, and recyclable building material. It will therefore be a crucial breakthrough to replace technical fibres with cultivated biological fibres for the reinforcement of timber structures. This is not only relevant for the strengthening of existing structures but above all can be applied in new timber-bamboo composite building elements. This combination makes use of the best properties of both materials, saving resources by introducing a high-strength lightweight material.

◂ Bamboo composite materials can be used as reinforcement elements in various applications.

▸ Test samples of the newly developed bamboo composite material.

Standardized products from cultivated building materials

Similar to the establishment of a material norm in earth construction, as described in the contribution by Christof Ziegert and Jasmine Alia Blaschek (see p. 40), research on bamboo composite materials needs to advance towards a standardization in order to develop a common determination base for designers and engineers. If this can be achieved, bamboo and other cultivated building materials have the potential to revolutionize the building industry.

The current homogeneous, world-spanning building industry no longer asks the most obvious questions: what materials are locally available? What is grown or cultivated? And how can I utilize these substances in the construction process? The quest for urban sustainability must be global in ambition, but it cannot be a matter of applying a universal set of rules and resources. Rather, sustainability requires a decentralized approach that acknowledges the global dimension and is yet, at the same time, sensitive to the social, cultural, aesthetic, economic, and ecological capacities of particular places to thrive and endure. Within such a setting, the most common plant growing in the developing regions of our planet will play an important role in economic and environmental terms if utilized as a cultivated and biologically compatible material by the building industry.

NOTES

1 Brink, F. E. and Rush, P. J. (1966), *Bamboo Reinforced Concrete Construction*. Defense Technical Information Center.
2 Glenn, H. E. (1950), *Bamboo Reinforcement in Portland Cement Concrete*. Engineering Experiment Station.
3 Yu, Xiaobing (2007), "Bamboo: Structure and Culture – Utilizing Bamboo in the Industrial Context with Reference to Its Structural and Cultural Dimension", doctoral thesis, Universität Duisburg-Essen, Germany.
4 Geymayer, H. G., and F. B. Cox (1970), *Bamboo reinforced concrete*. US Army Engineer Waterways Experiment Station.
5 Ghavami, K. (2005), "Bamboo as reinforcement in structural concrete elements", *Cement and Concrete Composites 27* (6), 637–649. doi: 10.1016/j.cemconcomp.2004.06.002
6 Ghavami, K. (1995), "Ultimate load behaviour of bamboo-reinforced lightweight concrete beams", *Cement and Concrete Composites 17* (4), 281–288.
7 Leelatanon, S., Srivaro, S., and Matan, N. (2010), "Compressive strength and ductility of short concrete columns reinforced by bamboo", *Sonklanakarin Journal of Science and Technology 32* (4), 419; Mahzuz, H., Ahmed, M., Ashrafuzzaman, M., Karim, R., and Ahmed, R. (2011), "Performance evaluation of bamboo with mortar and concrete", *Journal of Engineering and Technology Research 3* (12), 342–350;

Rahman, M., Rashid, M., Hossain, M., Hasan, M., and Hasan, M. (2011), "Performance evaluation of bamboo reinforced concrete beam", *International Journal of Engineering & Technology 11* (4), 142–146; Salau, M. A., Adegbite, I., and Ikponmwosa, E. E. (2012), "Characteristic strength of concrete column reinforced with bamboo strips", *Journal of Sustainable Development* 5 (1), 133; Sethia, A. and Baradiya, V. (2014), "Experimental Investigation on Behavior of Bamboo Reinforced Concrete Member", *IJRET: International Journal of Research in Engineering and Technology* 3 (2), 344–348.

8 Terai, M. and Minami, K. (2011), "Fracture behavior and mechanical properties of bamboo reinforced concrete members", *Procedia Engineering 10*, 2967–2972; Terai, M. and Minami, K. (2012), "Research and Development on Bamboo Reinforced Concrete Structure", Paper presented at the Proceedings of 15th World Conference on Earthquake Engineering, Lisbon.

9 Yamaguchi, M., Murakami, K., and Takeda, K. (2013), "Flexural performance of bamboo-reinforced-concrete beams using bamboo as main rebars and stirrups", Paper presented at the Third International Conference on Sustainable Construction Materials and Technologies.

10 Adewuyi, A. P., Otukoya, A. A., Olaniyi, O. A., and Olafusi, O. S. (2015), "Comparative Studies of Steel, Bamboo and Rattan as Reinforcing Bars in Concrete: Tensile and Flexural Characteristics", *Open Journal of Civil Engineering* 5 (02), 228; Khan, I. (2014), "Bamboo Sticks as a Substitute of Steel Reinforcement in Slab", *International Journal of Engineering and Management Research 4* (2), 123–126; PaulinMary, B. B., and Tensing, Dr. D. (2013), "State of The Art Report on Bamboo Reinforcement", *IJERA: International Journal of Engineering Research and Applications 3*, 683–686; Pawar, S. (2014); "Bamboo in Construction Technology", *Research India Publications* 4 (4), 347–352.

11 Hebel, D. E., Javadian, A., Heisel, F., Schlesier, K., Griebel, D., and Wielopolski, M. (2014), "Process-Controlled Optimization of the Tensile Strength of Bamboo Fiber Composites for Structural Applications", *Composites Part B: Engineering Journal* 67, 125–131.

12 Hebel, D. E., Heisel, F., Javadian, A., Wielopolski, M., and Schlesier, K. (2015), "Constructing Bamboo – Introducing an Alternative for the Construction Industry", *FCL Magazine Special Issue* "Constructing Alternatives – Research Projects 2012–2015 – Assistant Professorship Dirk E. Hebel (October 2015): 10–21.

13 Hebel, D. E., Heisel, F., Javadian, A., and Wielopolski, M. (2014), "Bamboo Reinforcement – A Carbon Alternative to Steel", paper presented at the World Sustainable Building Conference 2014, Barcelona.

14 Hebel, D. E., Heisel, F., Javadian, A., Lee, S., Müller, P., and Schlesier, K. (2016), "Engineering Bamboo – a Green Economic Alternative Part 01", *a+u* 16:05 (548), 162–167.

15 Hebel, D. E., Heisel, F., Javadian, A., Lee, S., Müller, P., and Schlesier, K. (2016), "Engineering Bamboo – a Technological Alternative Part 02", *a+u* 16:06 (549), 162–167.

16 Javadian, A., Hebel, D. E., Smith, I., and Wielopolski, M. (2016), "Bond-Behavior Study of Newly Developed Bamboo-Composite Reinforcement in Concrete", *Elsevier Construction and Building Materials* (122), 110–117.

17 Jawaid, M. and Abdul Khalil, H. P. S. (2011), "Cellulosic/synthetic fibre reinforced polymer hybrid composites: A review", *Carbohydrate Polymers* 86, 1–18.

18 Platts, M. J. (2014), "Strength, Fatigue Strength and Stiffness of High-Tech Bamboo/Epoxy Composites", *Agricultural Sciences* 5, 1281–1290.

19 Schober, K. U. et al. (2015), "FRP reinforcement of timber structures", *Construction and Building Materials* 97, 106–118.

20 Palma P. et al. (2016), "Dowelled Timber Connections with Internal Members of Densified Veneer Wood and Fibre-Reinforced Polymer Dowels", World Conference on Timber Engineering.